Micro-Synchrophasors for Distribution Systems

GRID DATA Meeting
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Chief Scientist
PingThings

Micro-synchrophasors for Distribution Systems

Three-year, $4.4 M ARPA-E OPEN 2012 project (2013-2016) to

- develop a network of high-precision phasor measurement units (µPMUs) and high-speed database (BTrDB)

- explore applications of µPMU data for distribution systems to improve operations, increase reliability, and enable integration of renewables and other distributed resources

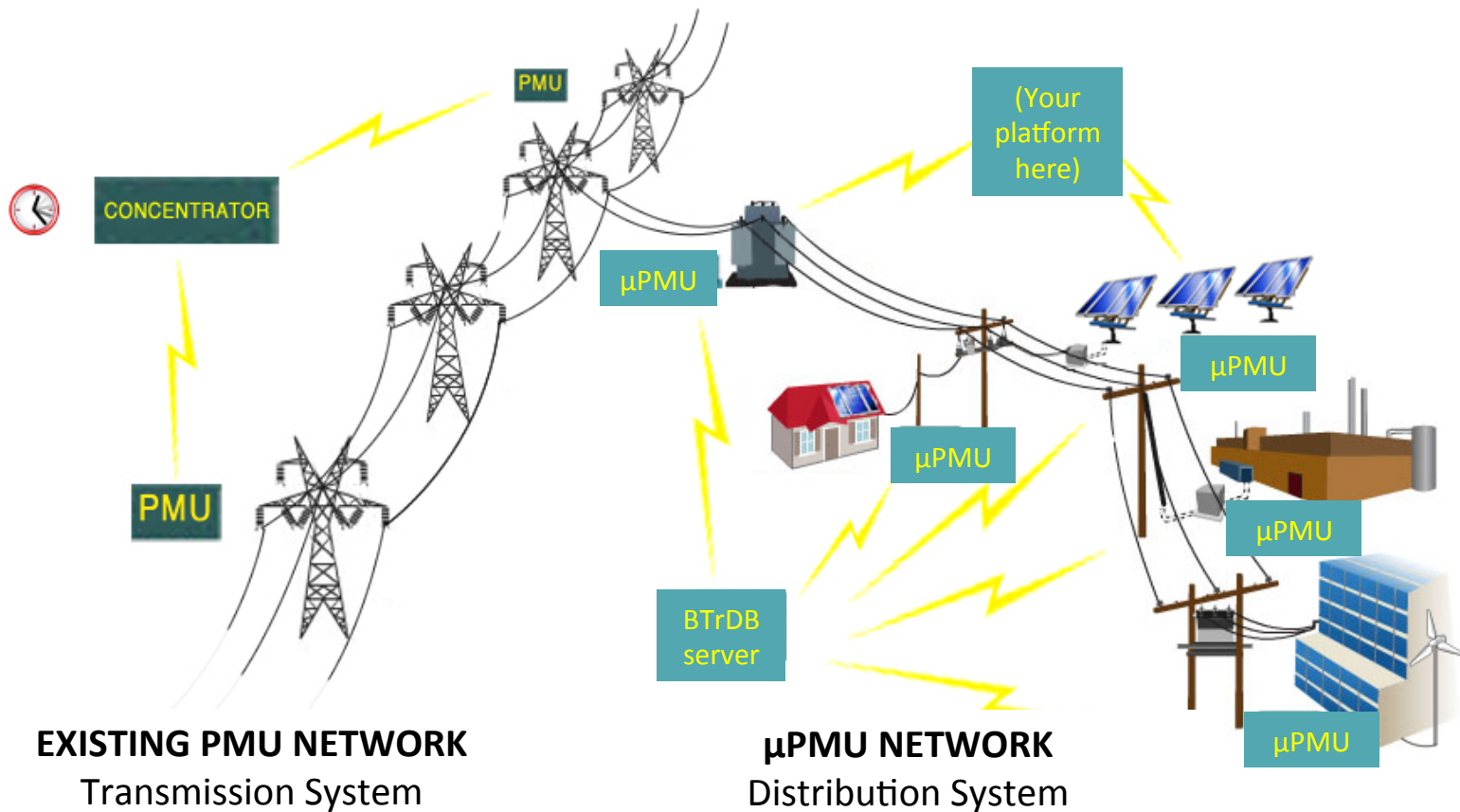- evaluate the requirements for µPMU data to support specific diagnostic and control applications

Micro-synchrophasor network concept:

Create visibility for distribution circuits behind the substation to support active management and integration of distributed resources

EXISTING PMU NETWORK
Transmission System

μPMU NETWORK
Distribution System

ARPA-E μPMU Project
Field installations:

UC Berkeley/LBNL

Southern California Edison

Riverside Public Utilities
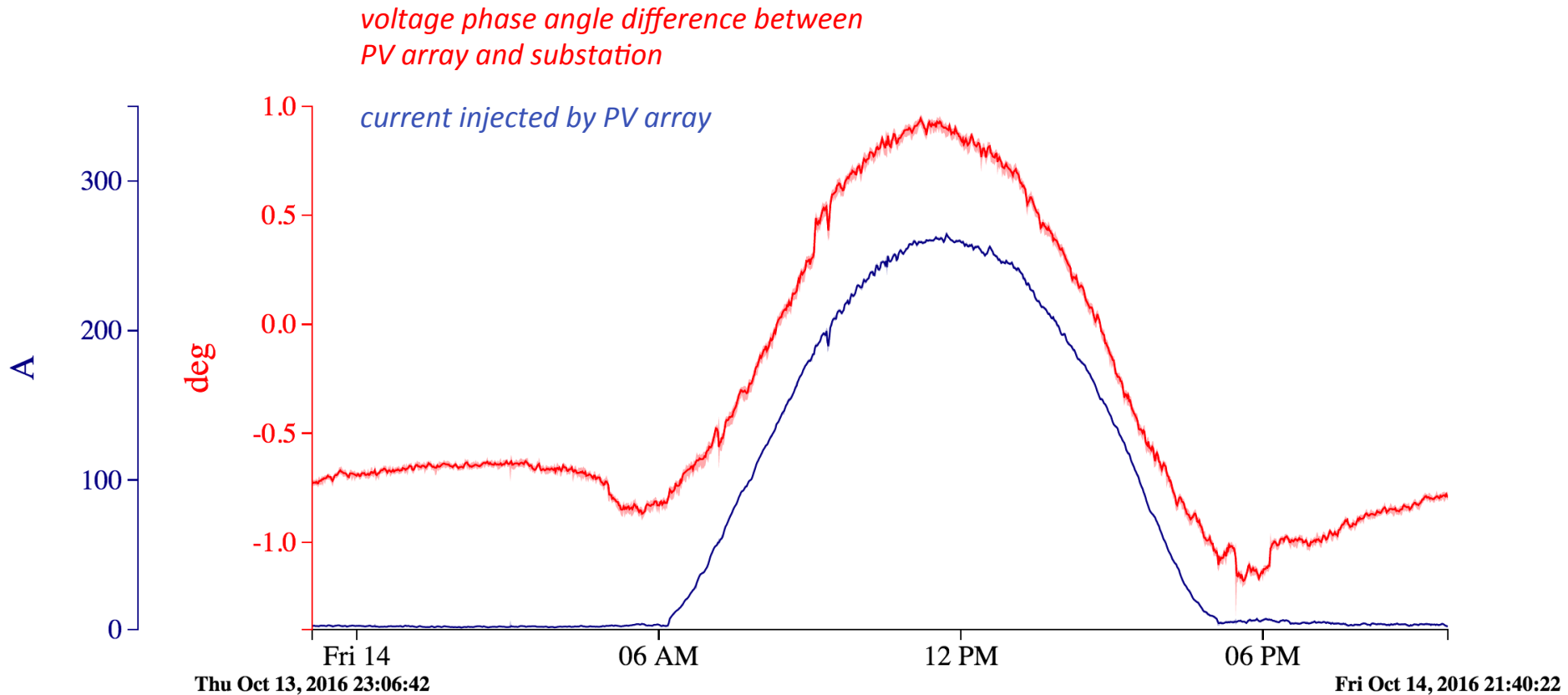
Alabama Power (Southern Co.)

Georgia Power (Southern Co.)

Tennessee Valley Authority
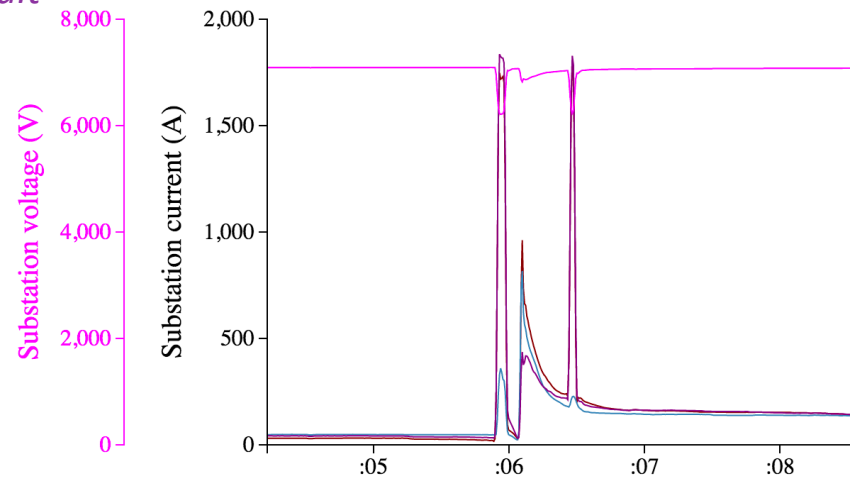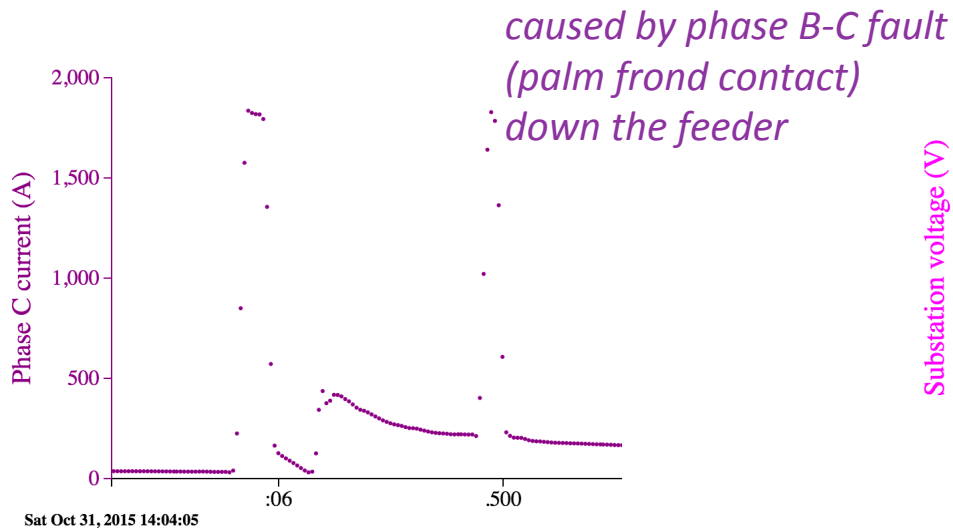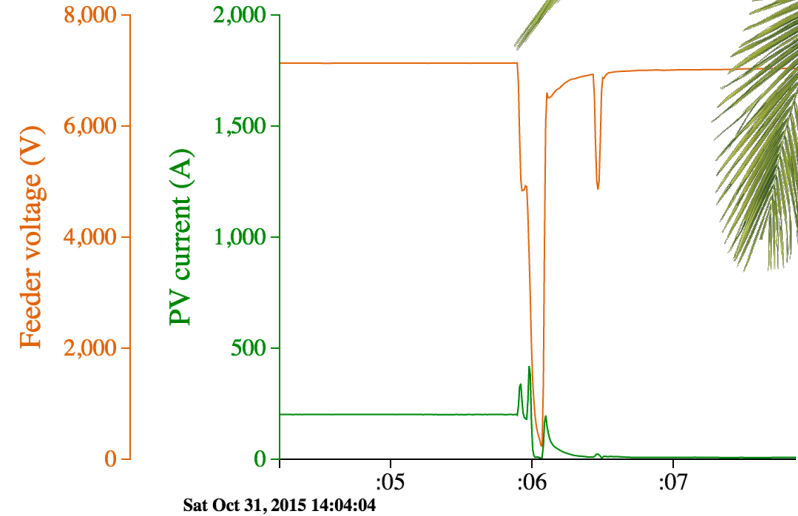
Pacific Gas & Electric Co.

Illustration: Measured phase shift along 12kV distribution circuit

voltage phase angle difference between PV array and substation

current injected by PV array

Use case example: Diagnose cause of DG unit trips

voltage sag

PV array trip

Sat Oct 31, 2015 05:19:30

Sat Oct 31, 2015 14:04:04

caused by phase B-C fault
(palm frond contact)
down the feeder
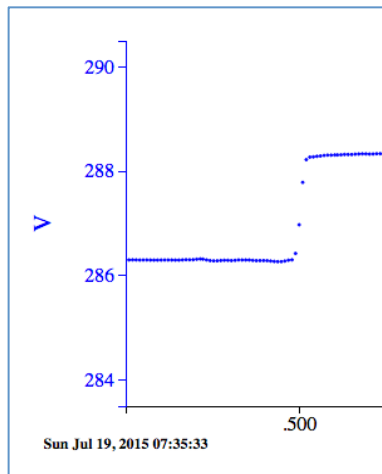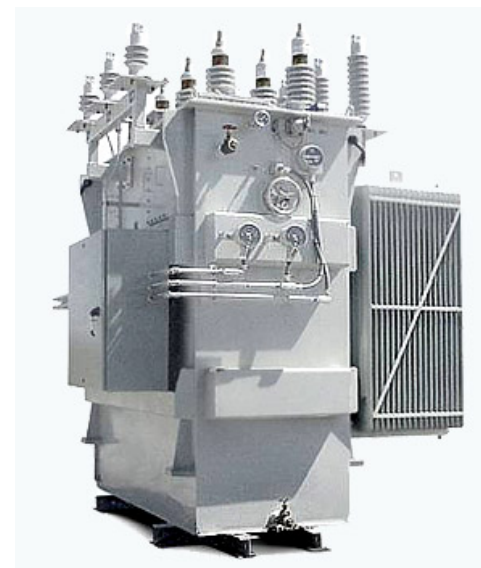
Sat Oct 31, 2015 14:04:05
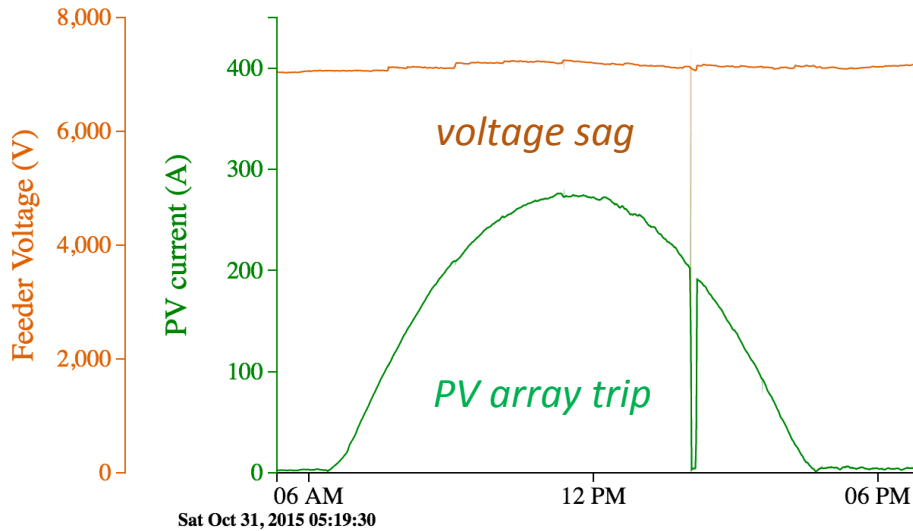
Use case: Detect normal and mis-operation of equipment
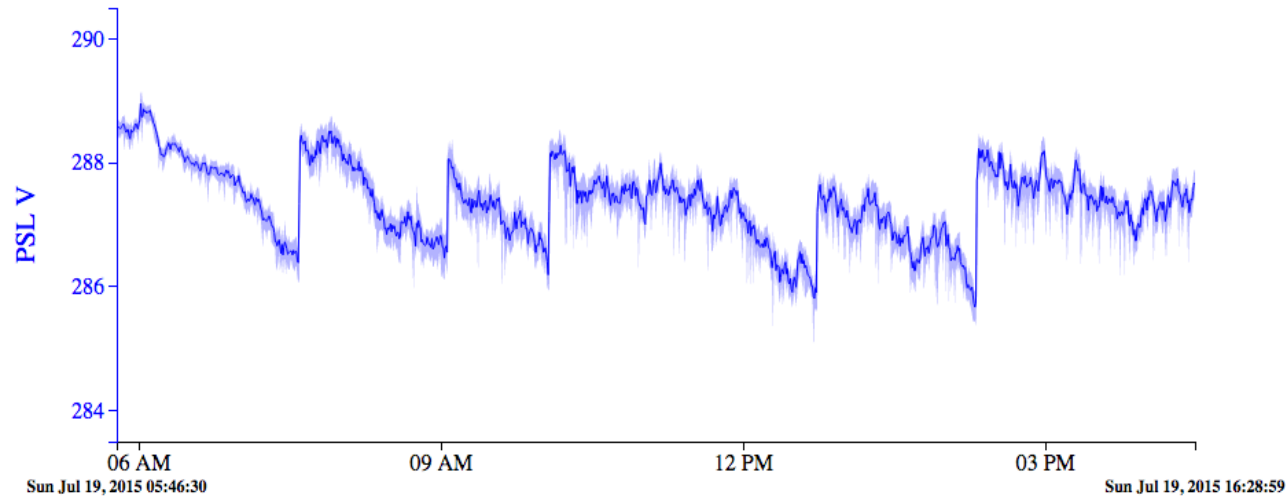
Tap changer at substation transformer steps voltage up and down as load changes over the course of the day

Tap change occurs over ~2 cycles Graph shows individual 120-Hz samples

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Use case: Detect normal and mis-operation of equipment

Curious voltage sag characteristically follows tap change operation

Secondary distribution voltage (V)

Voltage at Tap Changer (V)

Mon Nov 02, 2015 14:52:02

Transformer current (A)

Voltage at Tap Changer (V)

Mon Nov 02, 2015 14:52:04
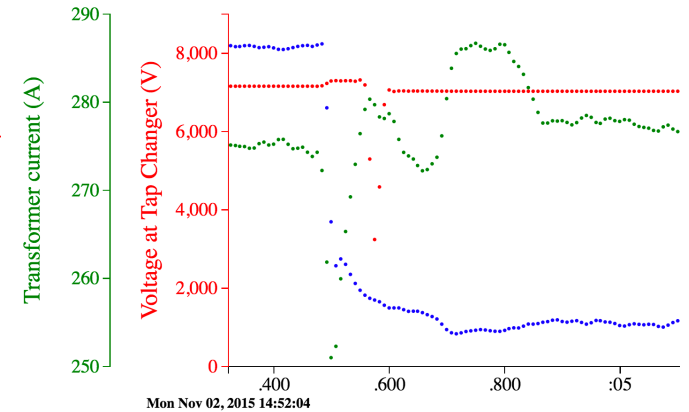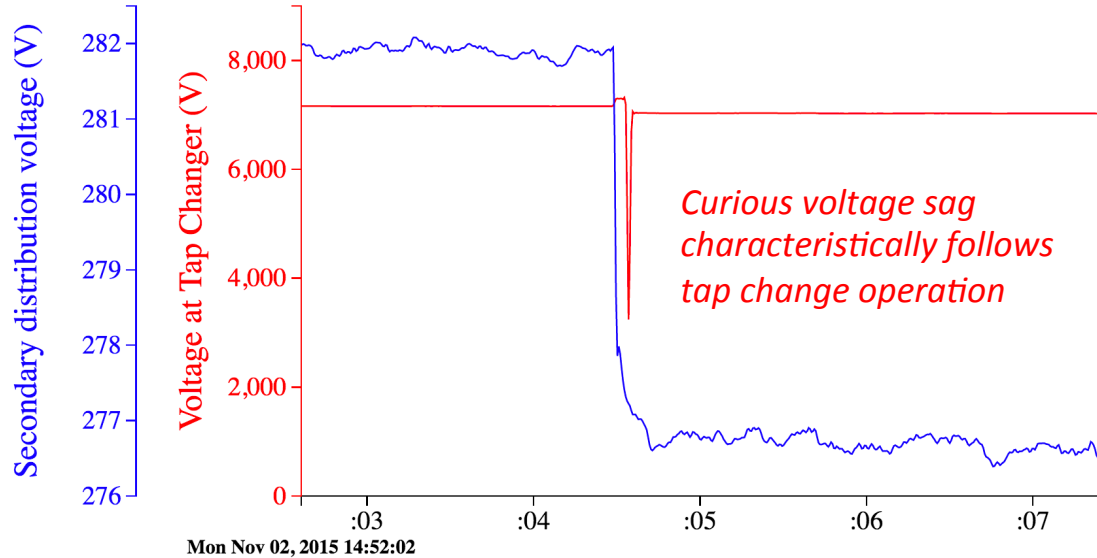
Example:
Anomaly in tap change signature gives early warning of transformer aging or incipient failure

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Key results

- µPMU instruments meet and exceed project goals
- Project has gathered 100+TB of distribution grid data at unprecedented fidelity and resolution
- BTrDB time-series storage and query processing performs 1400x faster than leading commercial or research solution, with unprecedented storage efficiency
    - plus unique additional functionality: fast change set, statistical summary, consistent versioning of data & data processing
- Strength of µPMU-based diagnostics derives from the time dimension and unique analytic framework:
    - measurement precision, temporal resolution, precise synchronization (PMU)
    - distillate framework, exponential tree searches at multiple time scales (general)
    - interactive analytics & visualization (general)
- Measurements have answered critical early research questions about phasor data and distribution grids, while raising many more
- µPMU technology has met with some interest in the utility industry; additional work through the research project will help applications be developed further by the private sector.

Micro-synchrophasors for Distribution Systems, Part 2

18-month, $2M **Plus-Up** extension project 2017-2018

Collaboration with three commercialization partners with different application foci:

Smarter Grid Solutions: *Planning, diagnostics & mitigation for high-penetration PV distribution*

Doosan GridTech (formerly 1EnergySystems): *Information infrastructure for distribution monitoring and control*

PingThings: *Stream analysis software for real-time grid data, T&D disturbance event detection and analysis*
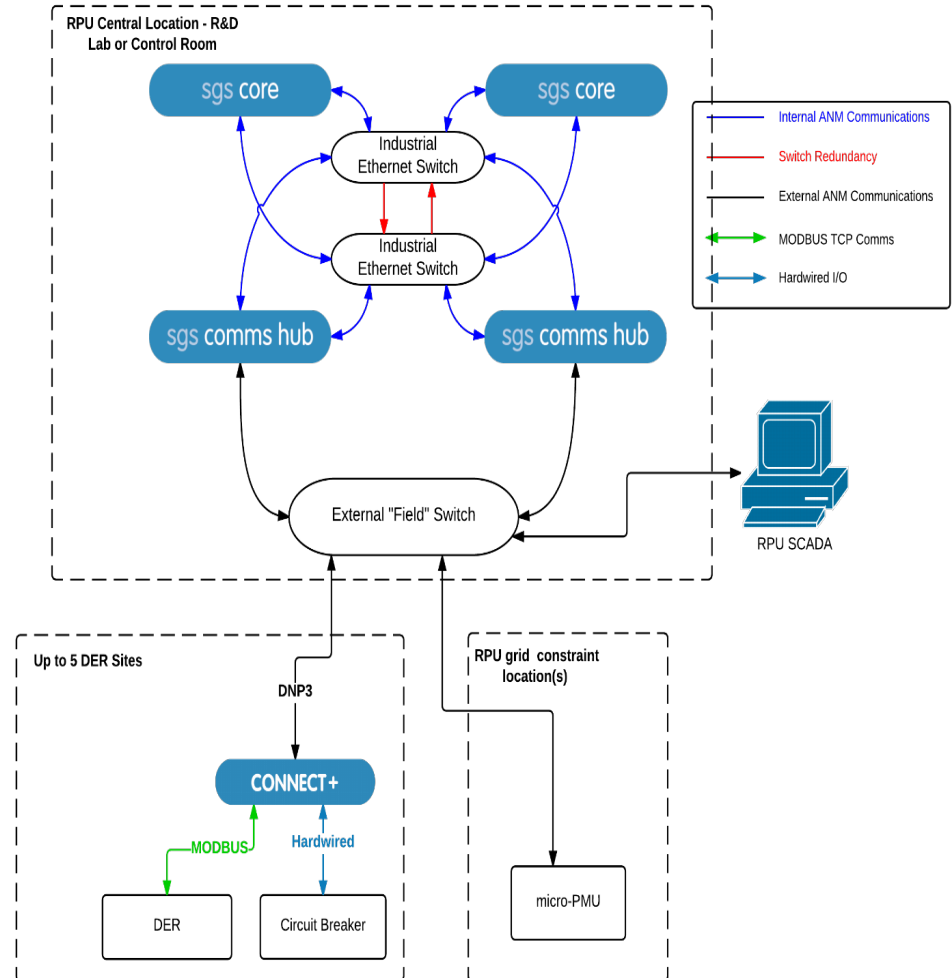
"Planning, Diagnostics and Mitigation for High-Penetration PV Distribution"

Partner: Riverside Public Utilities; Task lead LBNL

Project Objectives:

- Deploy SGS Active Network Management DERMS platform in one RPU trial circuit location

- Use µPMU and other utility data to inform advanced gird automation and control applications

- Evaluate the benefits µPMUs bring to planning and real-time control compared to traditional grid measurements
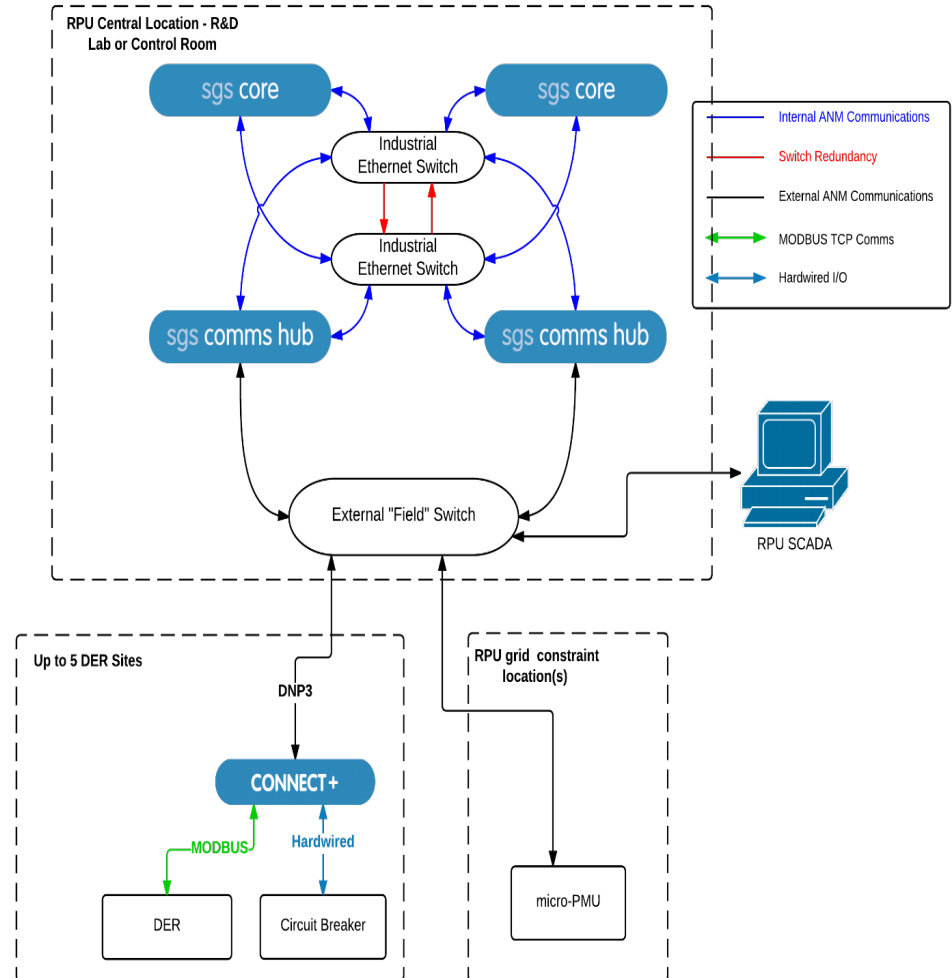
"Planning, Diagnostics and Mitigation for High-Penetration PV Distribution"

Value Proposition:

- Manage grids with high DER penetrations closer to their limits, using empirical data integrated into the diagnostic, planning and operational process

- Defer the need for grid reinforcements caused by the growth of distributed solar

"Information Infrastructure for Distribution Monitoring and Control"

Prospective utility partner: Austin Energy; Task lead CIEE

Project Objectives:

- Integrate μPMU data with Doosan GridTech's Intelligent Controller (DG-IC)

- Build a local information infrastructure to enable monitoring and control of circuit performance on a DER-intensive circuit, including solar PV and battery storage

- Create a data backbone to enable DER control schemes on a feeder that can scale across device types

"Information Infrastructure for Distribution Monitoring and Control"

Value Proposition:

- Intelligent recruitment of distributed resources, including energy storage systems (ESS), maximizes the value of these assets

- Extends life of other utility assets, such as voltage regulation devices

- Improve power quality for the customer

- Assure that DER satisfies local distribution constraints while serving needs of the transmission tier

PingThings + μPMU

PingThings
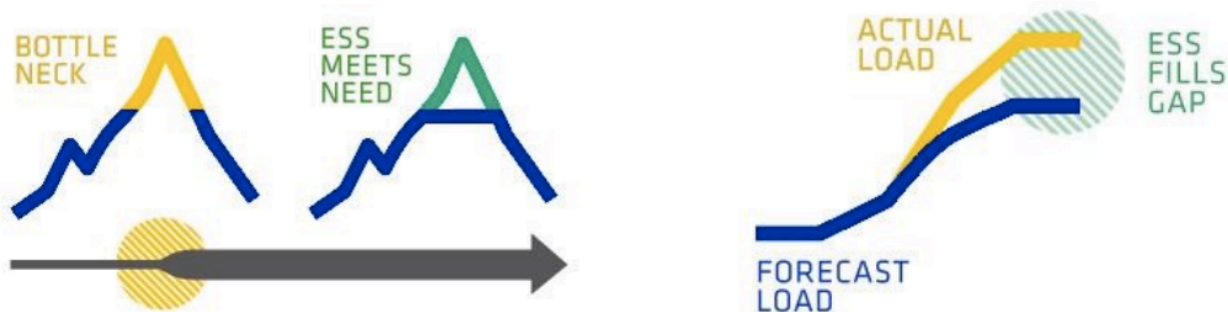
"Stream Analysis Software for Real-Time Grid Data"

Prospective utility partner: PG&E; Task lead CIEE

Project Objectives:

- Integrate μPMU data into Stream Analysis software

- Demonstrate application of Stream Analysis across transmission and distribution systems

- Study specific use case of geomagnetic disturbances (GMD) and their impacts

PingThings + μPMU

PingThings

"Stream Analysis Software for Real-Time Grid Data"

Value Proposition:

- Inform preventive measures to minimize costly damages from GMD (estimated 8-10 B$/yr)

- Detection of anomalies such as voltage sags supports situational awareness

- Better and faster forensic analysis of anomalies saves time, supports mitigation and ultimately prevention

- Understanding anomalies associated with variable and distributed generation supports appropriate measures by responsible party, whether utility or DG owner
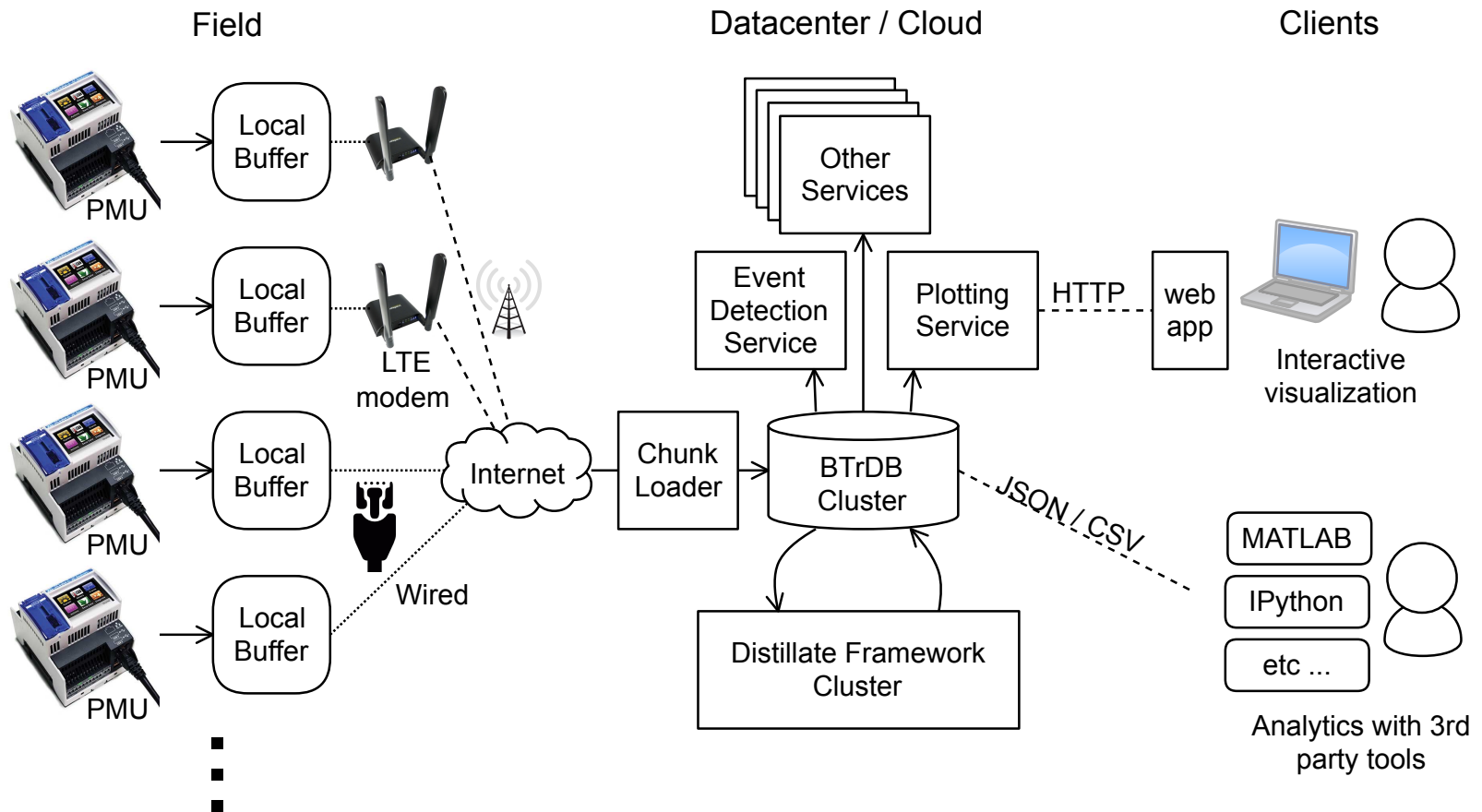
Cross-cutting activities relevant to GRID DATA

- Further development on Berkeley Tree Database (BTrDB)
- Interface between BTrDB and GridLAB-D
- LBNL Power Data portal

Berkeley Tree Database (BTrDB)

ARPA-E research project configuration: ca. 40 µPMUs sending 120 Hz data via Ethernet or 3G/4G wireless, 12 streams per device (voltage and current magnitude & phase angle)

Michael Andersen, UC Berkeley

Berkeley Tree Database (BTrDB) resolves the downsides of storing and utilizing large, high-resolution time-series data streams

- no need to compromise between data continuity, resolution, ease of access

- extremely fast searches (~200 ms for individual samples within months of 120-Hz data)

- performs online computation of data distillate streams (e.g. power, frequency, rates of change, differences between quantities)

- data available for viewing in plotter and downloadable through API for external analytic applications

- open source code available on github

Transformative Advances in BTrDB

- Distillation infrastructure with extremely fast change set identification
  - Operate real-time on many streams, with holes, out-of-order, etc.

- On-the-Fly statistical summaries over a multi-resolution store

- Multi-resolution search and process
  - Find 'needle' events in immense haystacks instantly
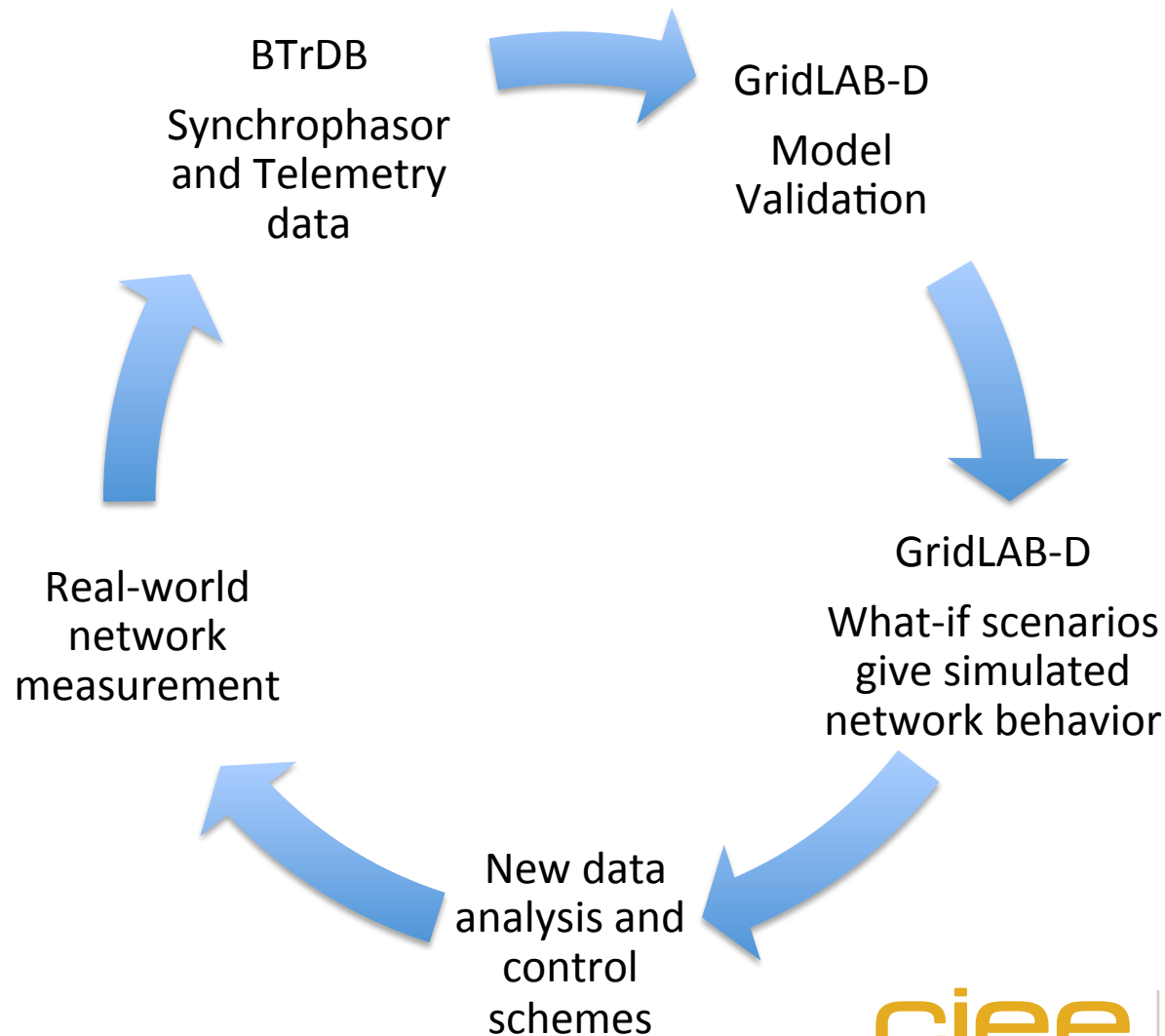 - Drill down exponentially to analyze

BTrDB + GridLAB-D

- GridLAB-D player objects enable external time-series data to be used in simulations

- BTrDB + GridLAB-D python script exposes time-series data in GridLAB-D player object format in a special buffer (named pipe or FIFO)

- GridLAB-D opens buffer as if it was a regular player file

- As each timestamp is read by GridLAB-D, python script retrieves next timestamp from BTrDB and writes to the buffer

- Python script can vary timestamp resolution

BTrDB + GridLAB-D

BTrDB
Synchrophasor and Telemetry data

GridLAB-D
Model Validation

GridLAB-D
What-if scenarios give simulated network behavior

New data analysis and control schemes

Real-world network measurement

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Power Data Portal
BERKELEY LAB

Mr. Plotter (BTrDB)

Visualize ARPA-E data via BTrDB.

Explore: New Interface

Visualize, explore, and download data via a new interface being developed. **Now Available**

Download

Download Open µPMU dataset raw data files over HTTP.

About

Can synchronized distribution level phasor measurements enhance planning for power flow and system control, security and resiliency in the modernized grid?

By installing a number of µPMUs in various locations in the electric distribution system and evaluating the data from them, the project aims to determine whether refined measurement of voltage phase angles can enable advanced diagnostic, monitoring and control methodologies in distribution systems, and to begin developing algorithms for diagnostic applications based on µPMU data.

Applications being studied include:

- State estimation and enhanced visibility for distribution system operators
- Characterization of loads and distributed generation
- Diagnosis of potentially problematic conditions such as oscillations or FIDVR
- Microgrid synchronization

Available datasets

A limited LBNL µPMU dataset is available for research collaborators to visualize and download.

Please reference this publication for citations:

Stewart E.M., et al "Open µPMU: A real world reference distribution micro-phasor measurement unit data set for research and application development," LBNL Technical Report 1006408, October 2016.

Additional power-related data will be available to visualize, explore, search, and download via this portal in the near future.

Acknowledgments and disclaimers

This research is sponsored in part by the U.S. Department of Energy ARPA-E program (DE-AR0000340).

The California Institute of Energy and Environment (CIEE) is leading this project together with Lawrence Berkeley National Laboratory (LBNL).

The manufacturer and prime contractor Power Standards Laboratory (PSL) is supplying and testing the technology, which is based on PSL's already commercialized PQube power quality recorder.

Disclaimer The information, data, or work presented herein was funded in part by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their

Resources

Read the ARPA-E Project Impact Sheet at
http://beci.berkeley.edu/wp-content/uploads/2016/12/UCB-External-Project-Impact-Sheet_11102016.pdf

Peruse live and archival μPMU data at
http://plot.upmu.org and http://powerdata.lbl.gov/

Learn about μPMU hardware at
http://www.powersensorsltd.com/PQube3.php

Participate in the NASPI Distribution Task Team (DisTT)
www.naspi.org

Go straight to the source for BTrDB at
https://github.com/SoftwareDefinedBuildings/btrdb

Contact me with questions at vonmeier@berkeley.edu

California Institute for
Energy and Environment

Ping**Things** • • • • •

Internet Scale, Real Time Stream Analytics

- An internet scale, real time stream analytics company anchored in data science

- Privately held with General Electric as one of several investors

- Member, active participant of IEEE, CIGRE, JSIS, NASPI…

- Currently working with utility clients in the Eastern Interconnect and WECC

- ARPA-E Grant participant working on µPMU analytics with LBNL, CIEE, UC Berkeley

@pingthingsIO

Operational PMU Data Coverage
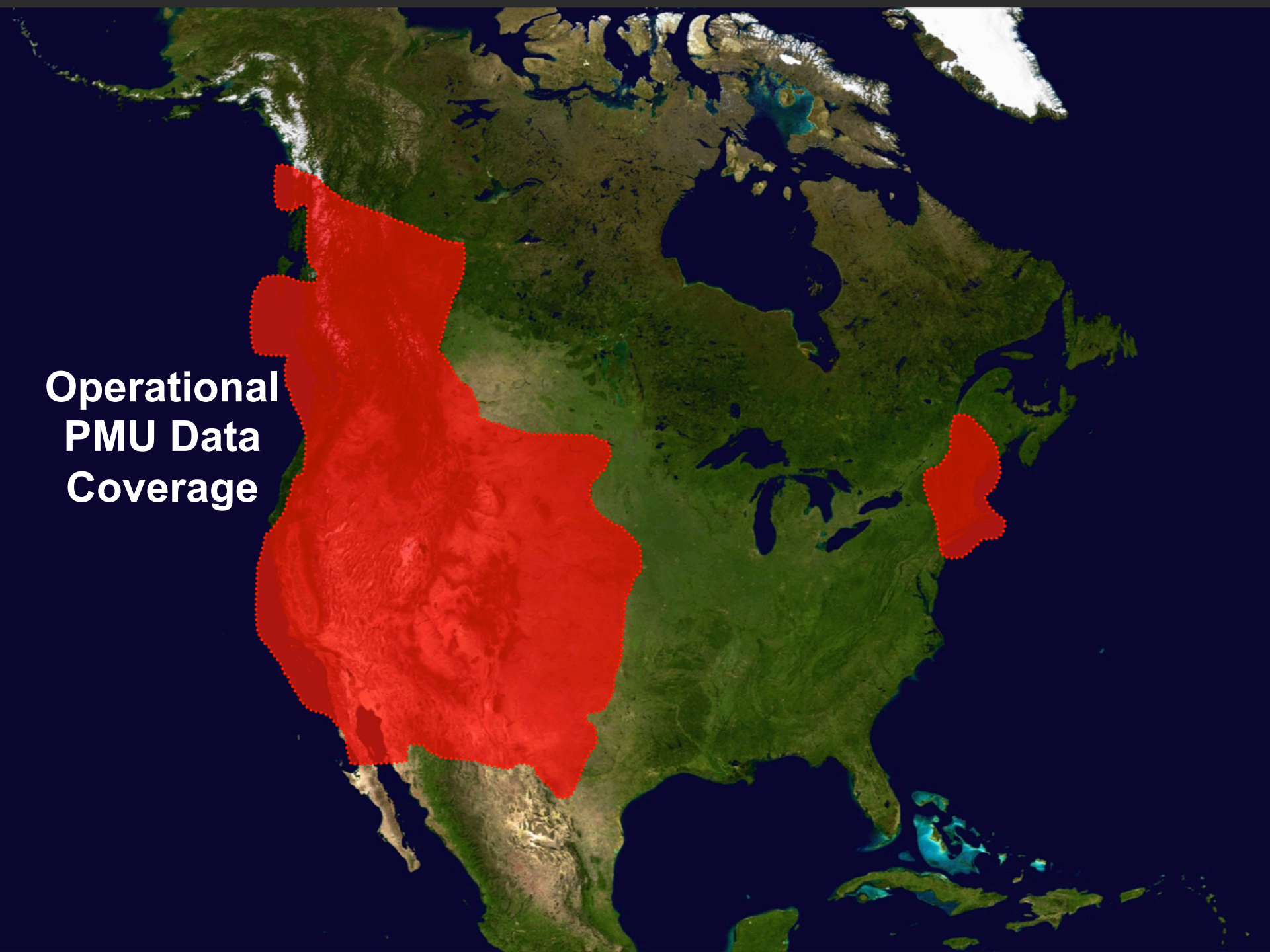
Tsunami

A cloud-based application that simulates global PMU data volume in real time.

Simulates

- thousands of PMUs and

- tens of thousands of data streams

Cloud-based, scalable

Cost effective to operate

Test framework for other products including data ingest engine

BTrDB Advancements

ISO NE

- October 2015 - July 2016

- All available PMUs

- 891 time series

- 577,368,000,000 data points

PG&E

- Core component to real-time data quality assessment tool

- Deployment in utility est. Feb 2017

Data Quality Assurance

- Real time data quality monitoring

- Monitors multiple aspects of data quality

- Web-based or off-line reporting

- Text/email real time alerts

- Designed to help identify location and root cause of the data problem with machine learning
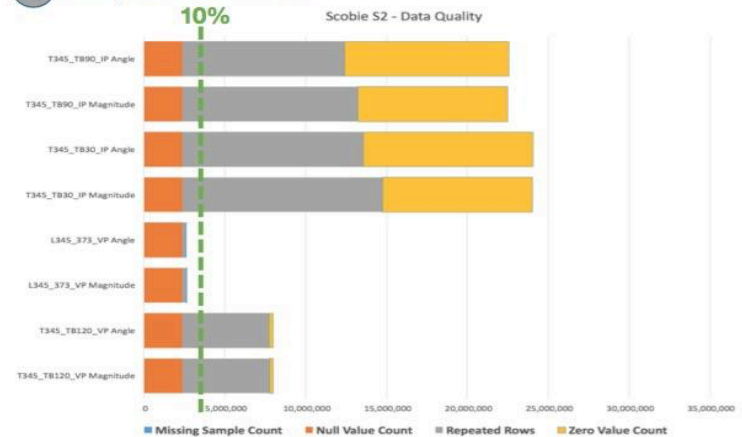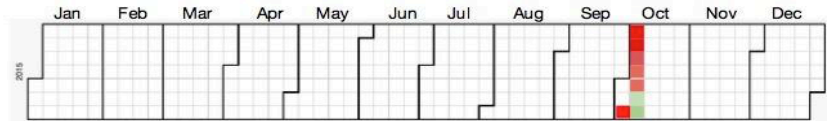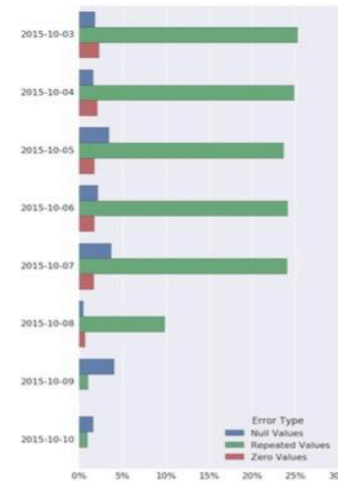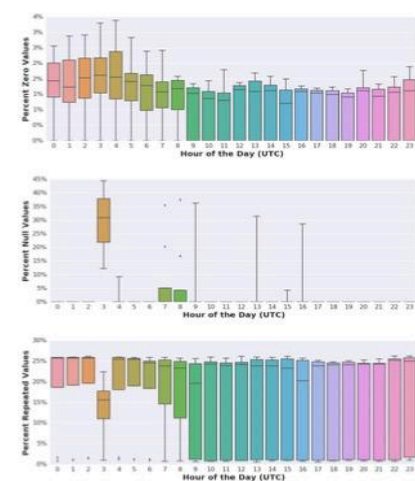
Examining GMD Effects on Distribution